4.3 Phase Three - Benthic Plume Source Terms

Data collected within this project (principally the August 1995 Owers Bank investigations) support the view that the benthic plume attributable to the hydrodynamic and mechanical interactions of the draghead with the seabed might be of much less quantitative significance than that generated at the surface through overspill and screening. The evidence collected by CBP methods has recorded only rare insights into the size of the benthic plume. No other observations appear to be available within the reviewed literature. Nonetheless, this has made study of the benthic plume no less important, if only to authoritatively clarify the actual characteristics.

A monitoring campaign was undertaken in order to sample the plume formed by the draghead. Analysis of simultaneous underwater video images has provided an estimate of the gross size, shape and morphology of the draghead plume in real time. Opportunity was also provided by the industrial partners to collect further CBP information on both the draghead benthic plume and the surface plume formed by a different class of dredge vessel. This section herein presents the results of the work carried out.

Weather conditions for the study were not ideal, following an unsettled period. Previous arrangements for undertaking the work in more favourable weather were thwarted by vessel breakdown, commercial requirements for the vessels elsewhere and adverse weather. It must be noted that the dataset collected during this campaign is not to the high quality of that obtained during earlier work within this project, principally as a result of the prevailing weather conditions experienced during the survey. However, this does not significantly detract from the conclusions reached.

4.3.1 Benthic Plume Sediments

To acquire source term data on the content of the benthic plume, it has been necessary to develop an economical yet efficient method of obtaining water samples from approximately 30m water depth. Various pumps and pumping arrangements were tested on three field trips, obtaining a limited number of samples. Considerable care was exercised to ensure that the capacity of the pump was such that any inertia of the sediments within the sample tube was overcome and that the samples were therefore representative, that is to say no separation of the fractions was introduced by the sampling system. The samples obtained were subsequently tested for total suspended solids concentration, and where possible, determination of the ratios of sediments less than and greater than 63µm (*i.e.* silts and sands, respectively).

Fieldwork was undertaken over a three day period in January 1997 from the 1300 tonne capacity TSHD ARCO Dee (Plate 4.3.1a), loading all-in and screened cargoes under normal operating conditions from Licences in the English Channel.

Plate 4.3.1a *TSHD ARCO Dee used for the benthic plume monitoring work*

The three sampling locations (designated A, B and C) were positioned; (A) approximately 1.2m above the base and in line with the rear end of the draghead; (B) 1.2m above the base and 0.5m inboard of the hinge point of the draghead / dredge pipe; and (C) 0.5m above and 0.8m in front of the draghead (see Plate 4.3.1b). Also visible on Plate 4.3.1b are the two SIT cameras used to observe the formation of the plume, enable measurements of scale and ensure the sampling points represented the fully formed plume.

Plate 4.3.1b *'California' Type draghead fitted to the ARCO Dee with two underwater cameras and three water sample positions*

Table 4.3.1a presents a summary of the samples obtained from the benthic plume using sampling tubes and pumps actually mounted to the draghead obtained. The nearbed background suspended solids (within 1.5m of the seabed) prior to the start of the survey were 18mg/l - 33mg/l (samples 1A and 1B). This relatively high background figure reflects the disturbed nature of the environment following the recent passage of two short gales. It can be seen from Table 4.3.1 that the average total solids concentration within the plume varies from 24mg/l close astern of the draghead to 31-37 mg/l closer to the side and slightly in front of the draghead. This is approximately twice that of the background conditions.

Evidence from the video imaging confirms that (a) background turbidity was higher than on previous video imaging campaigns; (b) development of the plume is highly variable over very short timescales; and (c) the developed plume is largely a result of pushing material in front of the draghead, rather than the subsequent scraping of the draghead over the seabed.

The draghead was trailed across the seabed without dredging to assess the effect of the near field suction. Samples 8 (A, B, & C), 9(A, B, & C) and 12(A, B & C) (all excluded from the calculation of the mean suspended solids value) were taken when the dredge pump was switched off and the draghead was on the seabed. These account for the highest suspended solids recorded during the campaign and are roughly twice that observed during normal dredging procedure. It is evident that the suction of the pump plays an important role in reducing the size of the benthic plume. Adjusting the speed of the vessel across the seabed to minimise the build-up of sediment in front of the draghead is therefore important for both efficient operation and reduction of the plume formed. This corroborates the conclusions reached in Davies & Hitchcock (1992) that the ‘bulldozer effect’ of the draghead motion plays a significant role in the efficiency of the dredging process (at the draghead end).

The silt content of the samples obtained when the dredge pump was not running are some 3-4 times greater than the *in-situ* concentration available from the prospecting data. This suggests preferential disturbance of the fine sediments further into the water column (such that they were sampled) with the larger sandy sized sediment not being thrown as far vertically. From the video images obtained about the draghead, it is evident that small fragments of broken shells are thrown further in the water column, as might be expected.

Sample Number	Total Solids (mg/l)	Silt (mg/l)	Sample Number	Total Solids (mg/l)	Silt (mg/l)	Sample Number	Total Solids (mg/l)	Silt (mg/l)
1A	33	n/d	1B	18	n/d	3C	44	n/d
2A	30	n/d	2B	19	n/d	4C	41	n/d
2A	20	n/d	3B	61	n/d	5C	27	n/d
3A	20	n/d	4B	56	n/d	7C	37	n/d
3A	21	n/d	5B	37	n/d	9C	22	n/d
4A	17	n/d	5B	17	n/d	10C	24	n/d
4A	23	n/d	6B	20	n/d	11C	22	n/d
5A	16	n/d	7B	21	n/d	12C	121	37
5A	20	n/d	8B	111	40	13C	28	n/d
6A	16	n/d	8B	32	n/d			
7A	19	n/d	9B	27	n/d			
7A	22	n/d	9B	120	56			
8A	20	n/d	10B	43	n/d			
9A	73	n/d	10B	64	n/d			
10A	24	n/d	11B	65	n/d			
11A	21	n/d	12B	105	67			
12A	20	n/d	13B	20	n/d			
13A	21	n/d						
mean	**24**	n/d	**mean**	**37**	**54**	**mean**	**31**	**37**

Table 4.3.1 *Summary of samples obtained during the benthic plume monitoring campaign, January 1997. Sampling equipment was mounted at three points on the (small) ‘California’ Type draghead of the TSHD ARCO Dee.*

Detailed analysis of the video images recorded during the campaign has enabled a preliminary calculation of the dimensions of the plume. This is established by comparison of known reference points on the draghead and their visibility or not during the recording. Only the video images obtained on the 15th January 1997 have proven suitable for interpretation, as has also been the case for the sample data due to poor weather conditions.

The draghead of the ARCO Dee is some 1.2m wide and may be expected to dig into the seabed some 0.35m (Davies & Hitchcock, 1992). Some penetration of the draghead below the surface veneer of sediments is necessary to avoid processing of recently deposited fine sands and silts.

The results from this analysis can reasonably be applied to slightly larger vessels and 'California' Type dragheads. It is known that the range of penetration of these types of draghead into the seabed is relatively small (compared with, for example, fixed visor types). The frontal area of contact of the draghead with the seabed is similar to that of a large beamtrawl. These have been studied to some extent and no significant impact determined (*see, for example,* Sydow *et al,* 1990).

We consider that the information obtained and processed herein provides a realistic assessment of the order of magnitude of the benthic plume source terms. Further field information would statistically refine the data.

From the video images, it appears important that the draghead maintains contact with the seabed to avoid the partial loss of suction as the draghead lifts off, and still exerts a disturbing effect on the seabed. This will be related to the seabed topography and geology, the weather conditions and the efficient operation of the swell compensator, and operator experience. The design of a 'California' Type draghead (two independent 'feet') is important in providing the improved continued contact with the seabed.

The ARCO Dee plume is estimated to vary between 0.67m^2 and 6.78m^2. The higher figures are considered to be present some 10% of the loading period and predominantly appears to be formed when the draghead loses contact with the seabed (due to seabed morphology and/or sea surface motion), reducing the near field suction effects. The smaller plume size is recorded when the draghead moves slowly across the seabed and occurs some 15% of the observed period.

Preliminary observations suggest from these data that the benthic plume averages approximately 2.7m^2 (± 2.1m^2) at the point of formation, about the draghead. From the data recorded in Table 4.3.1, we can calculate the following;

<u>FOR WORST CASE</u>
From field information:

speed over ground	= 2 knots
current speed against vessel	= 2.5 knots
speed of water past draghead	= 4.5 knots
velocity of water past draghead	= 8.334m/s

From video image processing:
6.78m^2 large plume observed for 10% of load
0.67m^2 smallest plume observed for 15% of load
2.70m^2 (mode) plume observed for 75% of load

Rate of material placed in suspension necessary to produce plume of average concentration 31mg/l is thus;

8.334m/s x 6.78m^2 = 56.50m^3/s
56.5m^3/s @ 31mg/l = 1.82kg/s
8.334m/s x 0.67m^2 = 5.58m^3/s
5.58m^3/s @ 31mg/l = 0.18kg/s
8.334m/s x 2.70m^2 = 22.5m^3/s
22.5m^3/s @ 31mg/l = 0.73kg/s

Hence for one, five hour load (18000 seconds), a vessel similar to the ARCO Dee would place into suspension about the draghead the following;

18000s x 10% x 1.82kg/s	= 3276kg
18000s x 15% x 0.18kg/s	= 486kg
18000s x 75% x 0.73kg/s	= <u>9855kg</u>
TOTAL	= 13617kg

of which up to 5992kg (44%) may be of silty sized material(<63µm).

From the video imaging and sampling of the benthic plume we can conclude that the quantity of sediment displaced into the water column by the draghead is very small, in essence accounting for less than one hundredth of the quantity of sediment otherwise returned overboard via overspill and rejection through screening. It is not surprising therefore that observations of the benthic plume using CBP techniques is rarely possible.

4.3.2 Plume Developed By The ARCO Dee Observed Using Continuous Backscatter Profiling (CBP)

During the same benthic plume monitoring campaign outlined in Section 4.3.1, opportunity arose to perform further CBP of the plume developed during aggregate dredging. Based on the results of the August 1995 monitoring campaign, it was hoped that good records would be obtained indicating the plume formed by the draghead, observed from positions close astern.

Weather conditions were not ideal for the conduct of CBP monitoring. It is clear from the data obtained before dredging commenced, that background suspended solids concentrations were higher than previously experienced at the site.

A vertical profile of samples obtained prior to dredging ranged from 8mg/l (surface), 11mg/l (midwater) to 14mg/l (4m above bottom). Once dredging commenced, further samples obtained from within the dredge plume near the surface ranged from 23mg/l to 53mg/l, all obtained within 200m of the stern of the vessel. A surface sample obtained within 20m astern of a spillway contained 159mg/l sediment, of which 10% comprised silty sized sediment (<63µm). Further midwater and near bed samples were not obtained due to equipment failure.

Figure 4.3.2a shows the ‘plume’ recorded using the ADCP[TM], before dredging has commenced. The backscatter is clearly due to aeration caused by the twin screws of the ARCO Dee.

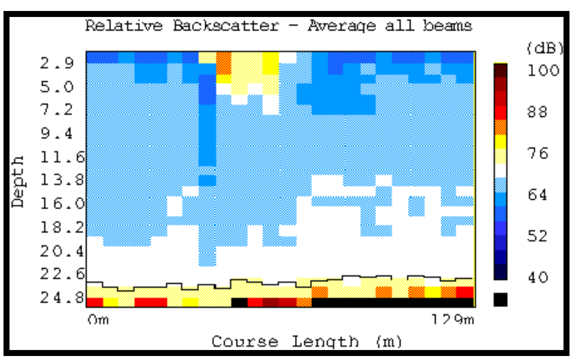

Figure 4.3.2a *CBP transect showing aeration caused by the twin screws of the ARCO Dee, before any dredging operations had commenced.*

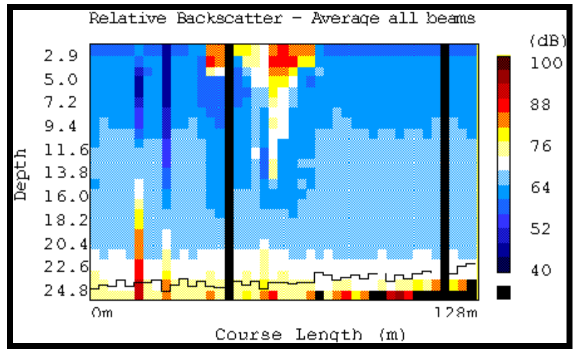

Figure 4.3.2b *CBP transect showing what is interpreted to be the plume formed by the draghead near the seabed. This plume appears not directly under the main vessel disturbance due to the angle of the survey path relative to the ship and draghead.*

Figure 4.3.2b records the only profile obtained (out of 56) on which the plume from the draghead is discernible, some 20m astern, before dredging commenced (*i.e.* the dredge pump was switched off). We know from the underwater video (Section 4.3.1) that the size of the draghead plume is exaggerated to some extent when in this situation, which is very unlikely during normal dredging operations. Also visible on Figure 4.3.2b is the plume caused by the very early stages of overflow, before any sediment reaches the seabed. Visual records from the survey boat indicate that this surface ‘plume’ may largely be aeration, with very little sediment observed.

Composite Figure 4.3.2c presents CBP data obtained from a series of transects across the plume of the ARCO Dee. It can be seen that the plume is quite small compared to the data obtained from the August 1995 campaign and is probably related to the ship size.

Plate 4.3.2 *View astern of the ARCO Dee showing the smaller plume formed by this size of vessel.*

The CBP data of Transects 1 and 2 clearly show the development of the ‘Density Current’ effect, accelerating the movement of material towards the seabed. Very little entrainment of sediment at the edges of the plume by turbulence is apparent in Transect 1. The quickly descending density current reaches the seabed virtually immediately underneath the dredger (within a ships’ length). The sediments will move to the seabed with a velocity considerably greater than the free fall, single particle velocities associated with their particle diameters, as determined widely by laboratory and field observations.

Transect 2 shows the bulk of the plume content reaching the seabed at a distance of only 180m astern (highest recorded backscatter levels). The plume becomes asymmetric near the surface, largely due to wind driven currents in the surface waters, in addition to the further input on the port side of rejected material.

Figure 4.3.2c

It is considered that the major constituent of the 'plume' recognisable in Transects 4-6 is actually of organic origin and this is explored in more detail in Section 4.4.

The wind and wave conditions during the time of the survey are important. Strong winds will induce drift in the surface layers thereby altering the advection rate for tidal currents alone. Wind will also generate surface waves which will tend to enhance diffusion by turbulence. The net effect of winds and/or waves will be to increase the rate of dispersion. Combined with the higher background levels of suspended sediments that may be present in coastal waters due to mobilisation of surface sediments, the detection time of plume sediments in unsettled conditions may be expected to be some time less than in calm conditions.

4.3.3 Discussion Of Benthic Plume Observations

In conclusion, we may therefore consider that the motion of the draghead upon the seabed causes only a small plume, commonly <3.0m^2 which is barely detectable from the surface using high resolution continuous backscatter profiling (CBP). The total velocity difference between the draghead and the water column will vastly change the advection, dispersion and suspended solids concentrations.

Suspended solids concentrations within the draghead plume have been measured to be of the order 30-40mg/l. The silt content may be enhanced, up to 44%, although the statistical reliability of this figure is low. Importantly, the likely significance and subsequent impact of such a plume is considered small, and in truth minor in comparison with the inputs of sediment (<1.0% by weight) to the surface waters through overspill and screening. In the coastal regions of the southern North Sea where the majority of marine aggregate extraction takes place, concentrations of 30-40mg/l may be largely indistinguishable from natural background conditions.

The type of draghead monitored is considered important, not only the size, but more importantly the design. Maintaining full contact with the seabed reduces the plume size. The test condition of disturbance without suction causes a significantly larger disturbance, not expected during normal working activities.

Importantly, observations from the deck of the survey vessel, and from the dredger (*for example, see* Plate 4.3.2), correlated with the water samples obtained, indicate that elevations of suspended solids 10-35mg/l above background levels of 10-20mg/l are clearly distinguishable by eye. That is to say, concentrations of suspended solids do not have to be significantly above background to be visible and consequently perceived as detrimental. The following section explores the hypothesis that the far field (away from the dredger) backscatter recorded is largely organic in origins, rather than sedimentological.